ROTARY DRYING FOR THRESHING PETALS FROM MARIGOLD FLOWERS

P. R. Armstrong, G. H. Brusewitz, M. L. Stone, N. O. Maness

ABSTRACT. *A rotary dryer was studied for drying and threshing petals from whole marigold flowers to obtain a petal material of relatively high xanthophyll concentration. Threshing efficiency varied from 70 to 90% for two of the three harvest dates while threshing rates varied considerably. The majority of threshing occurred when the petal moisture content declined to below 12% w.b. A greater moisture content differential exists between unthreshed petals and receptacles for drying temperatures of 71°C than for 60°C. Xanthophyll content declined with the length of time in the dryer and xanthophyll content for 71°C temperature drying was lower than for 60°C for the same drying time. Volume shrinkage of marigold flowers during drying was large. Flowers with unthreshed petal moisture contents below 12% w.b. occupied approximately 25% of their original volume.*
Keywords. Marigold, Xanthophyll, Poultry feed, Rotary dryer, Natural pigments.

Consumer demands for wholesome and natural food products has driven many food processors to seek food products and ingredients which are derived from natural sources (Walford, 1980). In the case of artificial food colorants, concerns for human safety have been justified and have led to the banning of some artificial colors. Artificial colors, synthetically or petroleum derived, are widely used although a suitable natural replacement would be well received.

Plant materials contain a wide range of pigment colors which occur naturally in leaves and fruit and provide an alternative source for food and pharmaceutical colorants. Among the plant pigments, carotenoids constitute a major potential source for yellow, orange, and some red colors (McWilliams, 1989). Xanthophylls comprise a group of carotenoids which are found in large quantities in marigold flower petals. Other plant materials such as yellow corn and alfalfa contain xanthophyl in much smaller concentrations. Currently, the major use of marigold-derived xanthophyll is by the poultry industry for broiler skin and egg yolk coloration. Much research has been directed toward understanding how xanthophyll is metabolized by poultry and factors which influence its effectiveness. (Fletcher et al., 1978, 1986; Janky et al.,

1985; Papa et al., 1985; Allen, 1993; Hencken, 1992; Piccaglia et al., 1998).

Rotary dryers are used for a wide variety of materials. The implementation of the rotary concept can vary considerably, but the fundamental advantage of this system is uniform drying due to mixing of the product. Modeling studies using rotary dryers have been done for several products. Schofield and Glikin (1962) examined several aspects of rotary drying fertilizers. Kelly and O'Donnell (1977) examined residence times in a cascading dryer for small particles. Alvarez and Shene (1994) and Shene et al. (1996) studied volumetric heat transfer and modeling in a rotary dryer for soya and fish meal, sawdust, and sand. Ramakumar et al. (1996) investigated rotary drying of rice paddy in a sand medium to decrease drying time compared to conventional drying methods. A multiple stage rotary design has also been studied for drying diced onions (Pelegrina et al., 1998).

Marigold flower production is currently centered in countries which have low labor costs needed for flower harvesting. Total annual world production is relatively small in land area which makes it a specialty crop. As such, little attention has been given to the development of specialized equipment to harvest and process flowers. This research examines a rotary process for simultaneously drying flowers and removing petals (threshing) to obtain a high quality xanthophyll product.

Recent research has examined drying characteristics of marigold flowers. Buser (1997) studied thin layer drying of marigold flowers to determine moisture diffusion rates. Petal components dried more quickly than the receptacle and the differential drying rates were used to describe moisture conditions for optimal petal detachment. Xanthophyll content of the petals was found to degrade through oxidation at high dryer air temperatures. Britton (1999) studied plate threshing as a method for separating dried petals from partially dried flower receptacles using a reciprocating plate and a corrugated rubber, endless conveyor belt. The system took advantage of the differential drying rates between the petals and receptacles.

The authors are **Paul R. Armstrong**, Assistant Researcher, **Gerald H. Brusewitz**, *ASAE Fellow*, Regents Professor, **Marvin L. Stone**, *ASAE Member Engineer*, Professor, Biosystems and Agricultural Engineering Dept., **Neils O. Maness**, Associate Professor, Horticultural and Landscape Architecture Dept., Oklahoma State University, Stillwater, Oklahoma. **Corresponding author:** Paul R. Armstrong, Oklahoma State University, Biosystems and Agricultural Engineering Dept., 214C Ag Hall, Stillwater, OK 74078, phone: 405.744.5289, fax: 405.744.6059, e-mail: <parmstr@okstate.edu>.

The variables examined were flower moisture content and the plate gap width between the conveyor and the plate. Flowers with high petal moisture content did not thresh well; a large percentage of the petals remained on the receptacle. Small plate gaps created excessive amounts of receptacle trash in the threshed petal material. Receptacle size, which changed with harvest, also affected the amount of trash in the threshed petal material. The major disadvantage of this system was that petal and receptacle moisture contents were difficult to control in order to obtain a product conditioned for optimal threshing.

OBJECTIVES

The primary objective of this research was to determine marigold petal threshing rates and efficiencies as affected by drying temperature, drum diameter, and harvest date. A secondary objective was to determine the flow behavior of flowers during rotation in the dryer, flower shrinkage, and flower moisture contents conducive to threshing. Xanthophyll content of the threshed petals was also examined during drying.

EQUIPMENT AND PROCEDURES
ROTARY SYSTEM CONCEPTS AND DESIGN

The fundamental operating concept of the rotary dryer/thresher is that agitation caused by rotation during drying is sufficient for threshing. This concept would exploit the differential rates of drying previously observed between petal and receptacle (Buser, 1997; Britton, 1999) to minimize trash in the threshed product. The rotary system allows mechanical detachment of the petals at the instant they reach a critical moisture content and become brittle. After detachment they can be removed from the drying environment and thus minimize the exposure time of the xanthophyll pigments to elevated temperatures. An additional advantage of the dual purpose system is the elimination of the need for handling between separate drying and threshing operations.

A simple batch dryer system was designed and constructed in which thresher efficiencies and the dynamic flow behavior of the flowers could be examined. A consideration in the design was the significant shrinkage of whole flowers during drying and the degree of mechanical agitation required for petal detachment. To allow for shrinkage, the drum on the rotary system was divided into nine radial sectors to help maintain airflow through the flowers (fig. 1). The sectors were formed using solid sheet metal dividers. The dividers directed airflow radially outwards from the center distribution hub through each sector. This arrangement provided better contact between the flowers and drying airstream than a non-sectored open system. A single drum (1.2 m diameter) was designed to accommodate two effective diameters of 1.2 m and 0.6 m. The smaller 0.6-m-diameter sectors were constructed within the drum to form three sectors. The outside of each drum sector was covered with 6-mm square wire mesh to contain the flowers but allow threshed material to fall through. Clear Plexiglas windows were installed on the sides of two sectors to observe flower dynamics and shrinkage during drying and rotation.

For experimental sampling purposes, three flow chutes were installed on the circumference of the dryer sectors to divert threshed material into a collection system. Material from each sector was used as a replication for each test condition (only three of the nine sectors were used for a single test to achieve three replications). Threshed material from the chutes dropped into a v-trough collector beneath the dryer and slid out a bottom opening into one of three collection containers. The dryer was elevated on 0.75 m tables to accommodate this collection system. Rotational speed of the dryer (1 rpm) was constant for all drying tests.

PROCEDURES

Two marigold flower varieties (I822 and EI236, Resource Seeds, Gilroy, Calif.) were used in the drying studies. Flowers were planted on research plots located on a commercial farm near Hydro, Oklahoma. Whole flowers
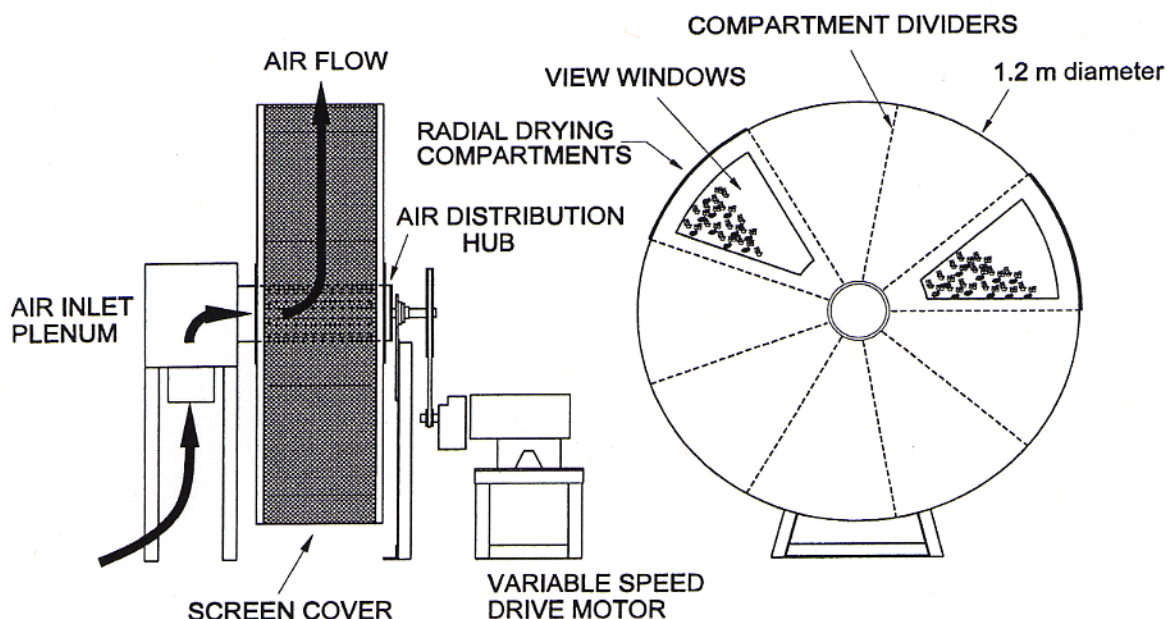

Figure 1–Schematic of the rotary dryer/thresher.

that had well-developed blooms were handpicked into black polyethylene bags and brought to the Stillwater Biosystems and Agricultural Engineering Research Lab where they were stored in a cooler (7°C) until used for tests. Storage time ranged from one to five days. Samples of flowers were taken before each test to determine the mass ratio of petals to receptacles and the moisture contents. A sub-sample of the fresh, wet petals were cut from the receptacle and frozen (–30°C) for xanthophyll analysis.

Drying tests were conducted over three flower harvests at approximately two-week intervals between July and August 1998. Four tests were conducted for each harvest using two drum diameters (0.6 m and 1.2 m) at two drying temperatures (60°C and 71°C). The 0.6-m drying tests were abandoned after the second harvest when it was found that the threshing action was not adequate to remove petals and is discussed later.

The general drying procedure was to load the three sectors of the dryer with flowers and start the dryer at the preset operating parameters for a particular test. Flowers were hand placed into the dryer until the total volume was loose-filled. The flower mass was recorded for each sector and was approximately 5 kg of fresh flowers per sector. Equal amounts of the two varieties were placed in each sector. The airflow at the beginning of all tests was adjusted to 0.33 $m^3/m^2/s$ based on the average cross-sectional sector area.

Threshed flower material that fell through each sector of the dryer screen was collected every 4 h and weighed. Moisture content (w.b.) of the threshed material was determined from samples by oven drying (103°C) for 24 h. Sub-samples of the threshed petals were placed in sealed plastic bags and stored in a freezer (–30°C) for later xanthophyll analysis. A sub-sample of 10 flowers was also taken from each sector every 4 h to determine moisture contents of the unthreshed petals and receptacles.

Measurements of the flower fill level were taken through the sector windows every 4 h for Harvest 1 to determine the time-shrinkage relationship. The flow behavior of the flowers was also observed by sketching the flower mass profile in the sector windows.

Xanthophyll measurements were taken on ground samples (Cyclone Sampling Mill, 0.5 mm screen, UD Corporation, Boulder, Colo.) of threshed petals for each collection period for Harvests 2 and 3. Approximately 1.5 g of marigold powder was weighed into a tared aluminum pan and placed in a dessicator with Drie-Rite, overnight in the dark, to remove excess moisture from the sample. Three 50-mg samples were processed according to the AOAC method 45.1.04 (AOAC International). Fifty milligram samples were placed in 100-mL volumetric flasks. Thirty milliliters of extractant (10 mL hexane, 7 mL acetone, 6 mL absolute alcohol, and 7 mL toluene) was added to the sample followed by 25 mL deionized water, and finally 2 mL methanolic KOH. The solution was mixed after each addition. Samples were then placed in a 56°C water bath for 20 min, cooled on ice for 5 min in the dark, and then allowed to stand for 1 h in the dark. Thirty milliliters of hexane was added to the sample and mixed followed by dilution to 100-mL volume with 10% sodium sulfate. Samples were then capped, mixed, and placed in the dark for 1 h. Two milliliters of the upper phase of the extract was then applied to a chromatographic tube containing a 7-cm layer of silica gel G/diatomaceous earth (50:50, W/N) topped by a 2-cm layer of sodium sulfate. Xanthophylls were eluted with hexane/acetone/methanol (80:10:10, V/V/N) and transferred into a 10-mL volumetric flask and brought to volume with elution buffer before spectrophotometric measurements were taken. Sample absorbence was measured at 474 nm using a Shimadzu UV 160U UV visible recording spectrophotometer (Shimadzu Corp., Kyoto, Japan). Results were quantitated according to AOAC procedure 45.1.04 and authenticated with alfalfa xanthophyll (Sigma Chemical Co., St Louis, Mo.) as a standard.

RESULTS AND DISCUSSION
GENERAL DRYER/THRESHER OBSERVATIONS
Flowers wilted relatively fast at the initiation of drying resulting in a substantial volume reduction. Volume-moisture content relationships are shown in figure 2.
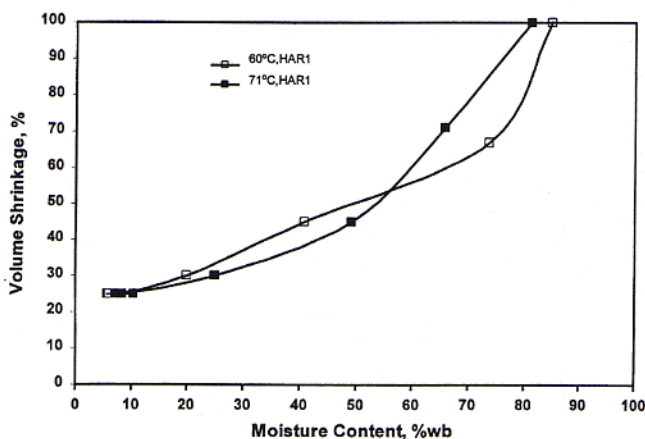
Figure 2–Flower volume shrinkage (% of original volume) versus unthreshed petal moisture content. Each point is the average of the three replications.
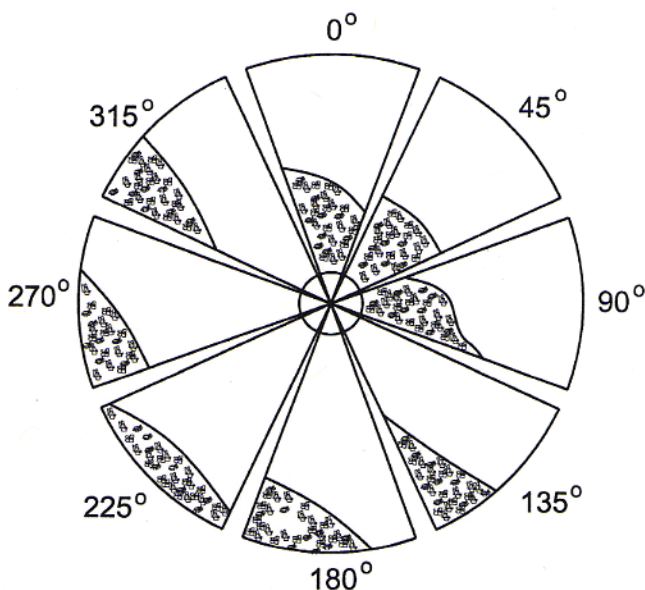
Figure 3–Flow characteristics of the flower volume during rotation in the dryer at a flower moisture content of 20% w.b.

Results obtained from two tests (Harvest 1, 60°C and 71°C drying temperatures for the 1.2-m-diameter dryer) show volume reductions of 75% at the end of drying. Profiles of the flower volume at different rotation angles, 20% MC, are shown in figure 3. At this moisture content, there are many instances where the air can divert around the flower mass and avoid going through the flowers.

Measurements of attached petal and receptacle moisture contents during drying showed that petal moisture content initially dropped faster than receptacle moisture content. Petals were observed to dry from the outer tips toward the point of attachment to the receptacle. After approximately 12 h of drying, moisture contents (unthreshed petal and receptacle) approached a value near 8% w.b. Threshed material moisture contents were always near 8 to 10%. The variability of moisture content for replications was small for all flower components. The maximum standard deviation of moisture content was 0.87 and thus the average moisture content of the replications is used in the following discussion of results.

Threshed petal material (measurable quantities greater than 10 g) generally started to appear after 12 to 20 h of drying. In all tests, a portion of the petals remained attached after several hours of drying even though they were dry and brittle and indicated inadequate threshing action. This was particularly apparent for the 0.6-m-diameter, 71°C dryer test in Harvest 1 where only 31% of the available material was threshed compared to 72% for the larger diameter, 71°C test. The smaller diameter was tested again during Harvest 2, 71°C, and then excluded from further tests after similar results were observed. The remaining discussion is thus based on results from 1.2 m diameter dryer tests at the different temperatures.

FLOWER COMPONENT MOISTURE CONTENT DURING DRYING

The moisture contents of the unthreshed petals (initially 77 to 85% w.b.) generally fell at an increasing rate until they reached about 25% MC (fig. 4); beyond this moisture content, the rate decreased and approached a constant value of 6 to 10% MC. The higher drying temperature produced a faster drying rate for all harvests. Drying curves follow the same basic trend for all harvest dates.

The moisture content differential between the receptacle and unthreshed petals (fig. 5) was largest between 8 and
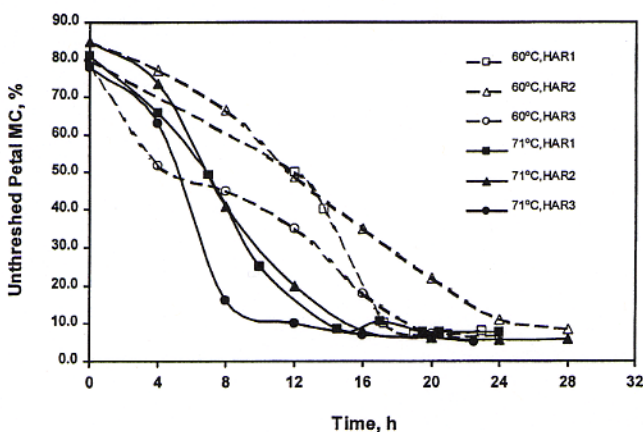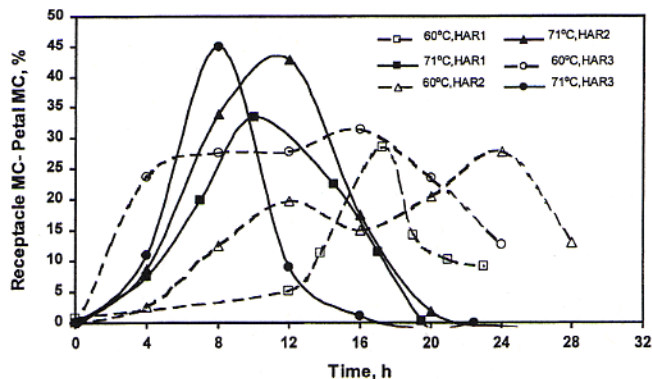
Figure 5–Difference between receptacle and petal moisture contents versus drying time. Each point is the average of the three replications.

12 h for the higher (71°C) drying temperatures and was about 50% higher than the 60°C drying. The large moisture content differential persisted for only 4 to 6 h for the higher temperature while the differential for the lower temperature lasted for at least 12 h. The threshed petal moisture content was relatively constant for all tests and ranged from 6.3 to 11.4% indicating that this is the critical range at which the petals are sufficiently brittle to be detached.

THRESHED PETAL YIELD

The yield of threshed material collected versus time is shown in figure 6. The threshed material is presented as a percentage of the total dry petals available for threshing. The total is based on the weight of fresh flowers initially loaded into each dryer sector, the mass ratio of the fresh petals to receptacles, and the initial flower moisture contents. The general shape of each curve is similar but threshing was achieved more quickly at the higher temperature for their respective harvests. The overall threshing efficiency (percentage of the total dry petals threshed at the end of the test) ranged from 18 to 90%. Harvest 2 produced lower threshing efficiencies. Threshing began to occur later during drying for Harvest 2 than for the other harvests and proceeded at a slower rate. The unthreshed petal moisture content for this harvest (fig. 4) shows that the flowers dried at a slower rate at the lower
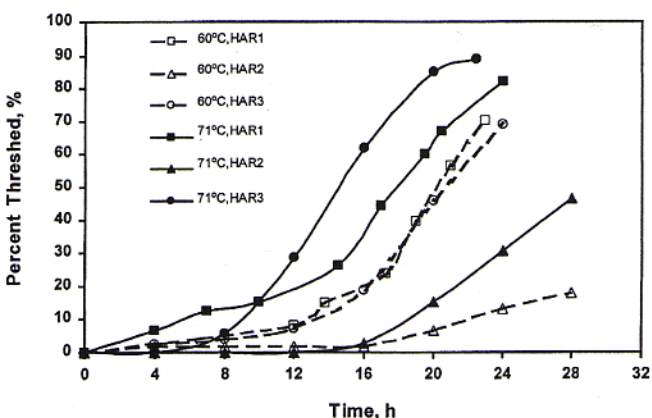
Figure 4–Unthreshed petal moisture content versus drying time. Each point is the average of the three replications.

Figure 6–Threshed petals as a percentage of the total available petals (dry mass) versus drying time. Each point is the average of the three replications.

temperature, but the higher drying temperature was similar to Harvest 1 flowers. Changes in the physical or physiological structure of the flowers between each harvest date may cause differences in the threshing efficiency. One observation was that the blossoms may have been more compact for some harvests and thus would not allow as much airflow into the center of the flower.

The effect of the unthreshed petal moisture content on the yield of harvested petals is shown in figure 7. Curves are similar in shape and show a step increase in amount of threshed material collected when the unthreshed petal moisture content decreases below 12%. Little threshing occurs at higher moisture contents. Although Harvest 2 did not have good threshing efficiency, figure 7, indicates that if drying had continued, nearly all of the petal material would have been threshed.

Some moist petal and non-petal material was collected as threshed material in Harvest 1 drying tests due to the flowers being infested with worms. Although the flowers appeared to be reasonably intact, worms had severed the base of the petal where it was attached to the receptacle, and agitation from drying caused some loose wet petals to fall off. The dry weight of these petals was a small percentage of the overall weight threshed.
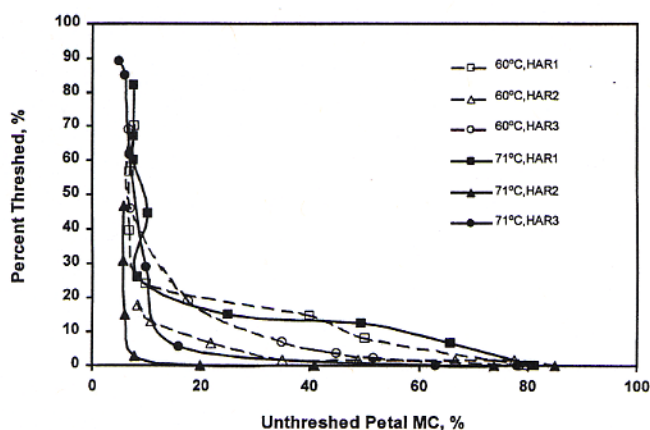

Figure 7–Unthreshed petal moisture content versus dry, harvested petals as a percentage of the total available dry petals. Each point is the average of the three replications.
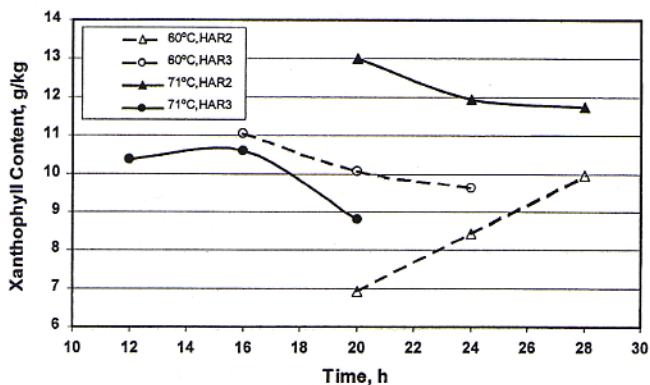

Figure 8–Xanthophyll content of threshed petals versus drying time. Each point is the average of the three replications.

THRESHED PETAL XANTHOPHYLL CONTENT

Xanthophyll content for Harvests 2 and 3 is shown in figure 8. Only samples from time periods where the majority of the threshing had occurred were analyzed for xanthophyll. Content generally declined with time in the dryer for all temperatures and harvests except for Harvest 2 at 60°C. The effect of drying temperature was not readily apparent from this data. The overall xanthophyll content of the combined threshed petals was determined to be about the same for each temperature for Harvest 3; 10.03 g/kg (71°C) and 10.17 g/kg (60°C), (Total content = [∑ content of collected sample × mass of dry threshed petals for each time period]/total dry threshed petal mass). Content was measured as grams of xanthophyll per kilogram of dry threshed petals.

The unusual response that Harvest 2 (60°C) displays, increasing xanthopyll content with respect to time, was not expected but could be attributed to the low threshing rate and efficiency. Xanthophyll content is most likely not uniform throughout the petal. If the petal tips have low xanthophyll and are the first part to thresh, then a rise in content might be expected as more of the inner petals are threshed at later drying times.

CONCLUSIONS

The rotary dryer attained reasonable threshing efficiencies for most of the harvests. Overall threshing efficiency (percentage of dry petals threshed/total available dry petals) was 70 to 90% for Harvests 1 and 3, for both temperatures. Threshing rates vary between harvests for the same drying temperatures while threshing rates for the same harvest are lower for 60°C temperature drying.

Nearly all threshing occurs when the unthreshed flower petal moisture content declines to less than 12% MC and petals become brittle. Drying rates of unthreshed petals are lower for 60°C temperature drying than they are for 71°C temperature drying and the differential between unthreshed petal and receptacles moisture content is greater for 71°C temperature drying.

Xanthophyll levels of the threshed petals declined with the length of time in the dryer; three of the four test results indicate this although Harvest 2, 60°C contradicts this. Literature indicates that elevated temperatures and time will result in destruction of carotenoids (Bauernfeind, 1981).

Volume shrinkage of the flowers during drying (approximately 75%) is a factor that needs to be considered in the design of the rotary dryer to maintain good airflow distribution within the drying material.

REFERENCES

AOAC International. 1995. AOAC Method 45.1.04. In *Official Methods of Analysis of AOAC International*. Gaithersburg, Md.: AOAC International.

Allen, P. C. 1993 Effects of formaldehyde fumigation of housing on carotenoid pigmentation in three breeds of chickens. *Poultry Sci.* 72(6): 1040-1045.

Alvarez, P. I., and C. Shene. 1994. Experimental determination of volumetric heat transfer coefficient in a rotary dryer. *Drying Tech.* 12(7): 1605-1627.

Bauernfeind, J. C. 1981. *Carotenoids as Colorants and Vitamin A Precursors*. New York, N.Y.: Academic Press.

Britton, B. 1999. Petal removal from marigold flowers with a parallel plate thresher. Unpub. M.S. thesis. Stillwater, Okla.: Oklahoma State University.

Buser, M. 1997. Thin-Layer drying of marigold flowers and flower components for petal removal. Unpub. M.S. thesis. Stillwater, Okla.: Oklahoma State University.

Fletcher, D. L., R. H. Harms, and D. M. Janky. 1978. Yolk color characteristics, xanthophyll availability, and a model system for predicting egg yolk color using beta-apo-8'-carotenal and canthaxanthin [in feed laying hens]. *Poultry Sci.* 57(3): 624-629.

Fletcher, D. L., C. M. Papa, and F. X. Tirado. 1986. The effect of saponification on the broiler coloring capability of marigold extracts. *Poultry Sci.* 65(9): 1708-1714.

Hencken, H. 1992. Chemical and physiological behavior of feed carotenoids and their effects on pigmentation. *Poultry Sci.* 71(4): 711-717.

Janky, D. M., R. A. Voitle, and R. H. Harms. 1985. The influence of different xanthophyll-containing feedstuffs on pigmentation of broilers reared in open and windowless houses. *Poultry Sci.* 64(5): 926-931.

Kelly, J. J., and P. O'Donnell. 1977. Residence time model for rotary drums. *Trans IChemE* 55: 243- 252.

McWilliams, M. 1989. *Foods: Experimental Perspectives*, 203-205. New York, N.Y.: Macmillan Press.

Pelegrina, A. H., M. P. Elustondo, and M. J. Urbicain. 1998. Design of a semi-continuous rotary drier for vegetables. *J. Food Eng.* 37(2): 293-304.

Piccaglia, R., M. Mauro, and S. Grandi. 1998. Lutein and lutien ester content in different types of *Tagetes patula* and *T. erecta Indust. Crops & Products* 8(1): 45-51.

Papa, C. M., D. L. Fletcher, and H. R. Halloran. 1985. Utilization and yolk coloring capability of xanthophylls from synthetic and high xanthophyll concentrates. *Poultry Sci.* 64(8): 1464-1469.

Ramakumar, M. V., G. S. V. Raghaven, and S. Javaregowda. 1996. Operating conditions for drying paddy in a rotating drum with sand medium. *Drying Technol.* 14(3&4): 595-613.

Schofield, F. R., and P. G. Glikin. 1962. Rotary driers and coolers for granular fertilizers. *Trans. Inst. Chem. Engs.* 40(3): 183-190

Shene, C., F. Cubillos, R. Perez, and P. I. Alvarez. 1996. Modeling and simulation of a direct contact rotary dryer. *Drying Technol.* 14(10): 2419-2433.

Walford, J. 1980. *Developments in Food Colours-1*. London, U.K.: Applied Science Publishers Ltd.